Evidence for Negative Water Feedback[1]

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Abstract: Positive linear climate feedback for combined water effects is shown to be incompatible with the Faint Sun Paradox. In particular, feedback values of ~2.0 W/m^2K^{-1} favored by current GCM models lead to non physical results at solar radiation levels present one billion years ago. A simple model is described whereby Earth like planets with large liquid water surfaces can self-regulate temperature for small changes in incident solar radiation. The model assumes that reflective cloud cover increases while normalized greenhouse effects decrease as the sun brightens. Net water feedback of the model is strongly negative. Direct evidence for negative water feedback is found in CRUTEM4 station data by comparing temperature anomalies for arid regions (deserts and polar regions) with those for humid regions (mainly saturated tropics). All 5600 weather stations were classified according to the Köppen-Geiger climatology [9]. Two separate temperature anomaly series from 1900 to 2011 were calculated for each region. A clear difference in temperature response is observed. Assuming the difference is due to atmospheric water content, a water feedback value of -1.5 +/- 0.8 W/m^2K^{-1} can be derived.

I. INTRODUCTION

The Faint Sun Paradox was first proposed by Carl Sagan [1] who pointed out that the geological evidence that liquid oceans existed on Earth 4 billion years ago appears incompatible with a solar output 30% dimmer than today. The sun is a main sequence star whose output is known to increase slowly with age. The total change in solar radiation over this long period turns out to be huge ~ 87 W/m^2. It has been argued that an enhanced greenhouse effect due to very high CO2 and/or CH4 concentrations could resolve this paradox [2]. However, recent geological evidence does not support CO2 as being responsible but instead the authors propose a greater ocean surface leading lower albedo as a likely solution [3]. Others have suggested that high cirrus clouds effectively warmed the Earth [4]. Although the atmosphere must have been very different before photosynthesis began, the presence of large liquid oceans still implies that clouds and water vapor played a similar role in the Earth's energy balance then, as they do today.

II. MODELS

All current IPCC models adopt net positive feedbacks for water vapor and clouds [6]. A doubling of CO2 increases TOA radiative forcing by ~3.6 W/m^2 causing a baseline surface temperature rise of about 1°C to restore global energy balance through increased outgoing Infrared [5]. GCM models predict larger temperature rises ranging from 2-5°C due to these positive feedbacks. What do positive feedbacks imply for the Faint Sun Paradox? For a change in forcing DS, a feedback strength F, and G0 as the baseline response, the temperature rise DT is given by

$$DT = (DS + F.DT)G_0$$

Black body radiation from the Earth's surface is the primary negative feedback to any temperature rise DT.

DT =DS/(1/ G_0 -F)   1/ $G_0 = 4\sigma T^3 = 3.75$ W/m^2K^{-1} T=288K

GCM model feedbacks F range from +1.6 to 2.5 with an average positive feedback of ~ 2.0 W/m^2K^{-1} [6].

The sun has brightened 30% over the last 4 billion years and current average incident solar radiation is ~342 watts/m2. Assuming a slow linear increase of solar radiation with time yields a net forcing increase of 0.02 W/m^2 every 1 million years. The temperature response to this forcing has been calculated for feedback values F=-2, 0, +2. This can be integrated backwards 4 billion years from current temperatures. The results are shown in Figure 1.

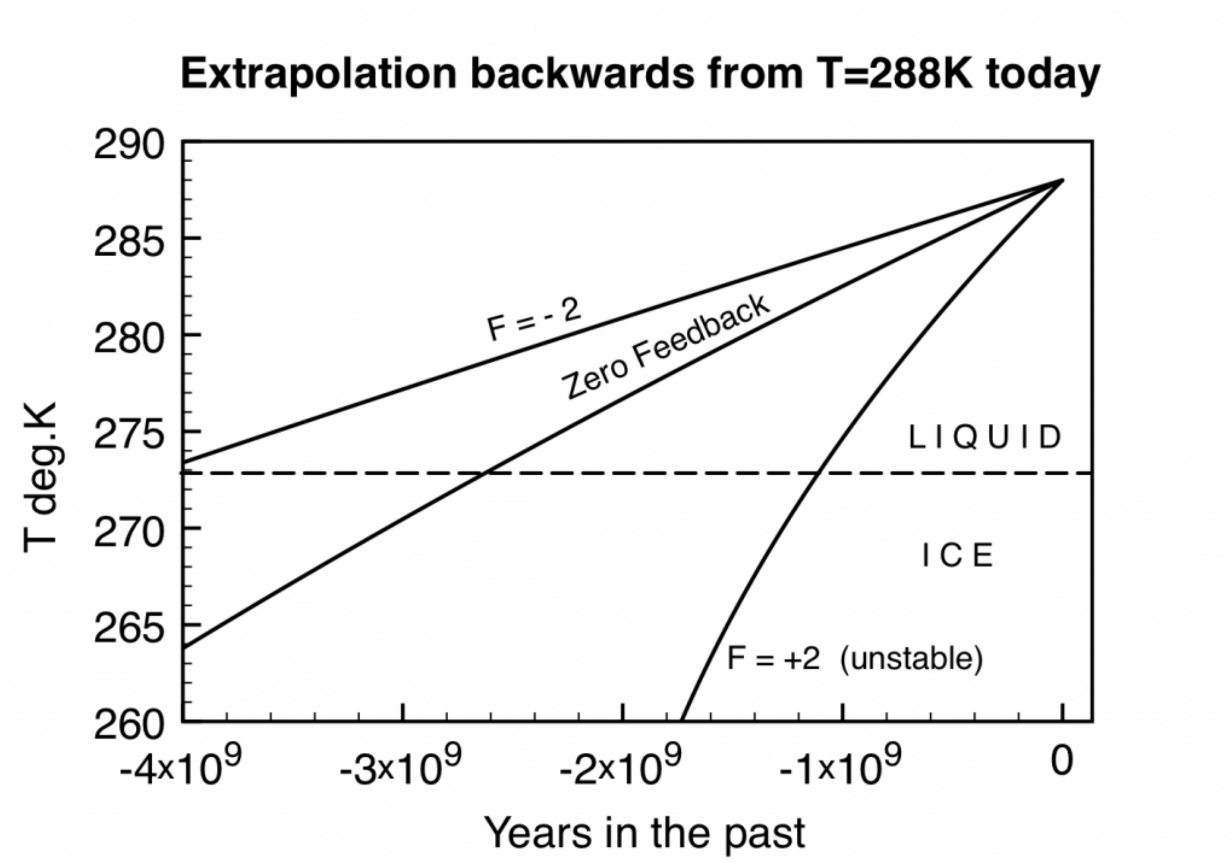

Figure 1: Past temperatures extrapolating backwards from today (T=288ºK) assuming different linear feedback values.

It is apparent that a simple linear positive feedback of +2 leads to unphysical results. The basic problem is that if the temperature falls sufficiently so that $4\sigma T^3$= F then a singularity occurs ~1.5 billion years ago. Instead a negative feedback value of -2 W/m^2K^{-1} is more compatible both with current temperatures and with the Faint Sun Paradox.

The evidence is that global surface temperatures have changed rather little over the Earth's history. It therefore seems likely that feedbacks were negative during the early lifetime of the Earth to avoid run away surface heating as the sun brightened. The continuous ~70% surface coverage of water on Earth has apparently stabilized global temperatures. A simple model of how this could work is described next, in analogy with Daisy World proposed by James Lovelock to justify Gaia theory [7].

III. WATER WORLD

Water world is a hypothetical planet 100% covered in water with an atmosphere similar to that on Earth but with no other greenhouse gas except water vapor. The climate is driven only by the thermodynamics of water evaporation and solar forcing. In all other respects conditions on Water World are exactly the same as on Earth except there are no seasons. Can such a water covered planet self regulate its temperature as the sun's output gradually increases? When the planet's sun is 4 billion years younger its output is 33% less ~ 274 W/m^2. Solar radiation slowly increases over the following 4 billion years to 342 W/m^2.

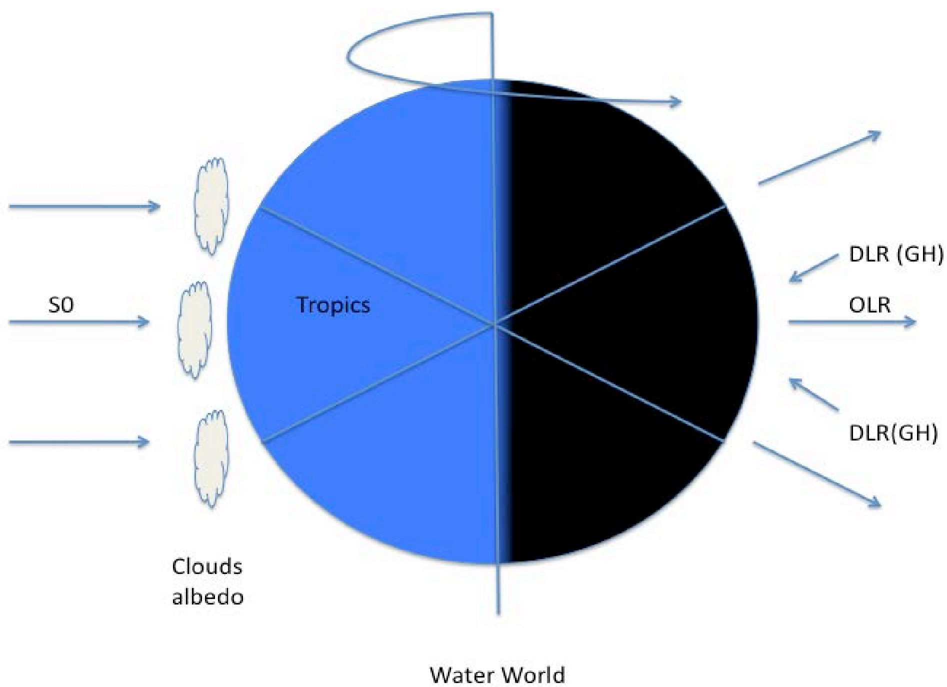

Figure 2: Schematic of Water World

The model has 2 basic assumptions. At low solar forcing epochs it is assumed that cloud cover is zero and evaporation mostly increases greenhouse warming. Further evaporation increases low convection clouds, reducing the planet's albedo. The global average temperature at any time is then a balance between these two effects. Ad hoc simple dependencies for both low clouds and net greenhouse effects on incident solar energy are assumed. Defining $x= S_0/342$ as the normalized solar radiation flux.

1. Low Cloud Cover (CC) is assumed to be linearly dependent on solar radiation: CC = 0.4x. The albedo for low clouds is taken as 0.5 so the planet albedo varies as 0.1+0.2x. For x=1 albedo equals that on Earth today ~ 0.3.

2. The normalized greenhouse effect g is assumed to depend inversely on x. The assumption is that g= 0.3/x giving a value of 0.3 on Earth today. 4 billion years ago g works out to be 0.45.

Defining SU as the surface outgoing IR, energy balance gives:

$(0.9-0.2x)\, S_0 = SU(1.0-0.3/x)$,

$SU = (342(0.9-0.2x)x)/(1-0.3/x)$ and assuming $T(x) = T_{now}\sqrt[4]{SU(x)/SU_{now}}$

This is easy to calculate and the results are shown in Figure 3.

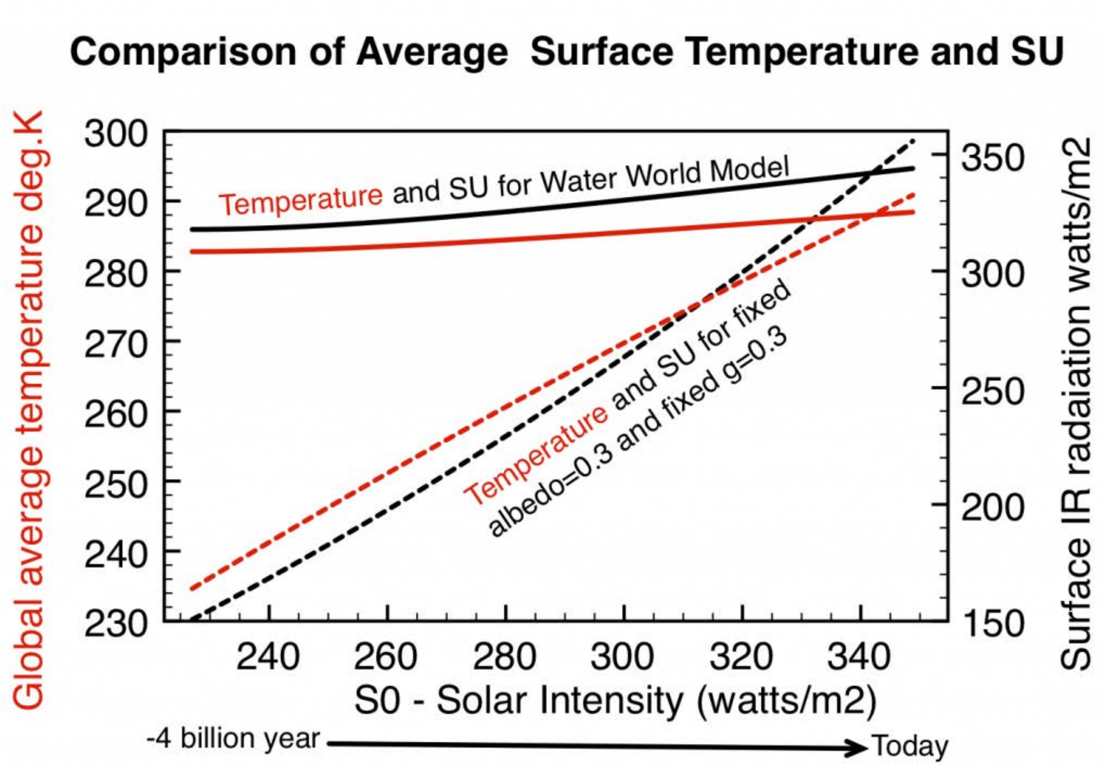

Figure 3: Water World model compared to a constant normalized greenhouse and albedo fixed at today's values.

Average temperatures change by just 5 degrees over 4 billion years. The presence of liquid water 4 billion years ago effectively rules out constant values for g and albedo in this model. Others have argued that a greatly enhanced CO2 greenhouse effect is responsible for warming in the early history of the Earth, however the geological evidence doesn't support it [3]. This simple model also predicts a low climate sensitivity of 0.2°C from a doubling of CO2. Is there any evidence for large negative feedbacks in recent climatology data?

IV. CRUTEM4 ANALYSIS

Water vapor feedback in recent climate data have been investigated by studying differences between regions with very low atmospheric water vapor (Deserts and Polar) and those regions with very large water vapor content (Tropical Wet regions). The latest CRUTEM4 data [8] consisting of 5500 individual station data covering global land areas has been studied. Each station was classified by indexing its geographic location against the Köppen-Geiger climate classification [9].

"ARID" stations are defined as those with precipitation values 'W' or with climate 'E' in [9]. These are situated either in deserts or in polar areas having the lowest atmospheric water column on Earth [10]. "WET" stations are defined as those within fully humid Tropical areas – Climate 'A' and precipitation 'f' in [9]. These are situated in tropical rain forests or year-round humid climates having the highest atmospheric water column on Earth [10]. Global anomalies have been calculated for both stations ARID and WET stations independently using the same algorithm as used for CRUTEM4. The results are shown in Figure 4.

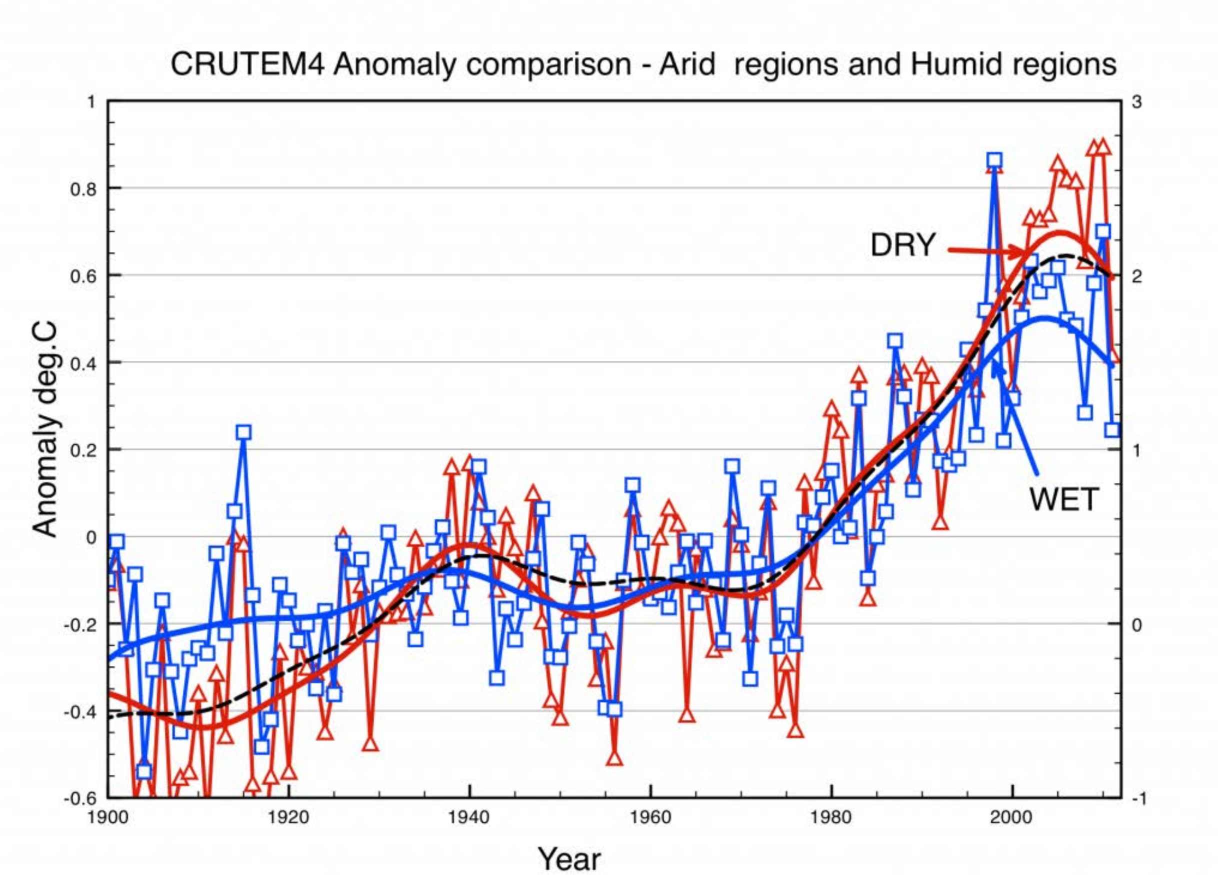

Figure 4: Temperature anomalies for ARID (DRY) stations in red and WET stations in blue. The smooth curves are FFT smoothed curves. The black dashed curve is an FFT smooth to the full CRUTEM4 global temperature anomalies.

There is a clear trend in the data that ARID stations warm faster and cool faster than WET stations. They respond stronger to changes in external forcing. The WET humid stations respond less than both the ARID stations and the global average.

Climate change is complex and global so it is reasonable to assume that both anthropogenic and natural forcing are reflected in the temperature anomaly data. For a given forcing DS the consequent change in temperature anomaly is gDT where g is a gain factor. The period between 1900 and 2005 is used to measure the temperature rise for each region DT1 and DT2 as given in Table 1. DS is assumed to be global in extent.

Table 1 : Temperature changes for ARID and WET regions and their ratio. Errors on DT are derived from differences between the FFT smooth and a linear fit.

Period	**DT1(DRY)**	**DT2(WET)**	**DT1/DT2**
1900-2005	1.1 +/-0.1 ºK	0.8+/- 0.1 ºK	1.4 +/- 0.2

Heat inertia effects due to nearby oceans may cause tropical climates to react slower than desert regions, but not over such long periods. If positive feedbacks from increased water evaporation lead to enhance warming then this should be apparent in the tropics, and this is not observed. In fact the opposite is the case implying a negative feedback. Under the assumption that net water feedback F is present only for the WET stations (taking F=0 for ARID stations) then F can be measured from the data:

$DT1/DT2 = 1 - G_0F$, where $DT1 = G_0DS$ and $DT2 = G_0 (DS+FDT2)$

For $G_0^{-1} = 3.75$W/m2K gives **Water Feedback F = – 1.5 +/- 0.8 W/m2K-1**

This is compatible with the value needed to resolve the Faint Sun Paradox. As has been pointed out by Lindzen [11] and others, much of the Earth's heat is transported bodily through evaporation and convection to the upper atmosphere where IR opacity is low and can then escape to space. Therefore water feedback effects depend mostly on the water vapor content of the upper atmosphere. Increased evaporation, convection and consequent rain out could then result in lower humidity in the upper atmosphere. This is a possible mechanism for negative feedbacks in the tropics. Such effects would be largely absent in ARID areas, which have no local sources of evaporation.

V. CONCLUSIONS

The Faint Sun Paradox effectively rules out constant positive climate feedbacks for water. The evidence supports the hypothesis that the Earth's oceans have stabilized temperatures for the last 4 billion years. It is proposed that the net effect of a surface with 70% water coverage self regulates Earth's climate. A simple model that demonstrates how this could arise has been described. The model leads to average temperatures increasing by just 5 degrees over 4 billion years. This leads to predicted negative feedbacks from water of about -2 watts/m^2/ºC. Direct evidence that the temperature response from arid and humid land regions on Earth is different has been identified in CRUTEM4 data. Assuming that these divergences are only due to atmospheric water vapor differences, a measured negative feedback for water of 1.5+/-0.8 watts/m^2/ºC is determined. This agrees with that needed to explain the Faint Sun Paradox.

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Postscript: The above paper was submitted to Geophysics Research Letters on April 25th. The editor later rejected it on the grounds that "*the work appears to represent an incremental advance in our understanding of a problem that has already received attention in the peer-reviewed literature, and extends its conclusions beyond what is supported by the research methods and results*". You are invited to decide for yourself whether that is true or not.

Note 1. Friends of Science comment:

The water feedback calculated here is due to all changes associated with a change in atmospheric water vapour. The IPCC separates this into several feedbacks, including water vapour feedback, lapse rate feedback and cloud feedback, etc. Therefore, the water feedback given here should not be compared to climate model water vapour feedback, but should be compared to the sum of all feedbacks.